Renewable and Sustainable Energy Reviews 14 (2010) 438–445

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A survey of China's renewable energy economy

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ARTICLE INFO

Article history:
Received 18 May 2009
Accepted 13 July 2009

JEL classification:
D24
O33
Q41

Keywords:
China
Biofuel
Biomass
Renewable energy

ABSTRACT

This paper surveys China's renewable energy economy, focusing particularly on renewable energy laws and programs, the lessons that can be learnt from the current literature, and the implications of that literature. Gaps in the literature on China's renewable energy economy include the need for more comprehensive econometric studies. The literature may also benefit from more collaboration between renewable energy economists and agricultural economists.

Contents

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1364-0321/$ – see front matter
doi:10.1016/j.rser.2009.07.029

1. Introduction

China is the largest and fastest growing emerging economy in the world. China's aggregate GDP reached 3.31 trillion US dollars by 2007 and its annual GDP growth rate has approximated 10% over the last two decades [1].[2] Correspondingly, China has experienced a period of extremely high-energy consumption which likely will continue for some decades [2]. China's aggregate primary energy consumption was 961.4 million tonnes oil equivalent in 1997 and had grown to 1863.4 million tonnes oil equivalent by 2007 [3]. While primary energy consumption has only risen by 8.1% in OECD countries and by 24.6% for the whole world in the last decade, the increase has been nearly 100% for China during the same period, making China now the second largest energy consumer, behind the United States [3].

This rising demand has turned China from a net energy exporter to a net energy importer and is becoming a source of global political tensions. China's energy production was 1.7% more than consumption in 1995 but consumption had surpassed production by 11.4% in 2007. This switch is even more marked for petroleum products. Imports supplied only 18.3% of China's oil consumption in 1995 but the import share reached 49.3% by 2007. As a result, China's net imports of petroleum and products have more than doubled, from 75.8 million metric tonnes in 2000 to 183.9 million metric tonnes in 2007 [1,3]. The costs and policy implications of China's growing energy reliance have been recognized [4]. This growing reliance on the global market for its petroleum supply has also raised economic concerns and political tension for China's energy security [5–7]. China's rising energy demand has increased global pressure to seek out new energy sources [8].

However, even faced with such an unfavorable energy situation, China's energy efficiency is comparatively low. For example, in 2005 China's energy intensity was 0.91 tonnes oil equivalent per thousand US$ GDP at 2000 prices compared with 0.32 for the world as a whole and 0.195 in OECD countries [96]. There is considerable debate about the major factors responsible for the higher energy intensity in China and its trend [9–13]. Given its size and high-energy intensity, any improvement in energy efficiency in China will affect world energy demand and in turn the world energy price [2]. Concomitant with this high-energy intensity, China may already be the world's largest emitter of CO_2 [14], posing a great challenge for China to implement Kyoto Protocol.

This survey is organized as follows: Section 2 discusses the motivations for reviewing studies of China's renewable energy economy. The next section has a brief review of the context of China's renewable energy laws and policies. Section 4 reviews previous studies on China's renewable energy economy, which is the core section of this paper. In addition to summarizing themes in the existing literature, there is discussion of what can be learnt from existing studies and what gaps are there in existing studies of China's renewable energy economy. Section 5 identifies some areas for future study of China's renewable energy economy and the last section proposes some suggestions for moving this literature forward.

[2] Exchange rate of Chinese yuan to US dollar is 7.6:1 on the 2007 price base [1].

2. Motivation for reviewing China's renewable energy economy

Following three decades of rapid economic growth and rising demand for energy products, Chinese residents are becoming more environmentally aware. Consequently, policy makers have begun to acknowledge the need for cleaner and more renewable sources of energy. Continued movements in this direction will see the share of coal in total energy consumption decline further, with the share of renewable energy (e.g., nuclear energy and hydro energy) increasing rapidly. However, China's renewable share (6.63%) of nuclear and hydro energies is only 55% of world average (11.99%) in 2007 [3].

Moreover, with over 60% of the population still living in the countryside, biomass resources are a major source of rural household energy consumption and also one of the biggest sources of rural environmental pollution. For example, between 2004 and 2006 China's rural households consumed, on average, 193.8 million tonnes of firewood, 363.5 million tonnes of stalks and 6964.1 million m^3 of biogas. In total, these biomass resources are equivalent to 272.6 million tonnes of coal and account for 75.8% of total rural energy consumption [15]. Since most of this biomass was directly combusted, reliance on this energy resource causes serious environmental pollution [16].

Given its importance to both global energy balances and pollution, the literature on China's renewable energy economy still has many gaps. A few topics have been extensively investigated, for example, regional potential for biofuel and biomass production [17,18], some specific and technical renewable energy programs [19–23], and the changing structure of rural energy consumption [24–28]. But many other important issues, such as grain-based bioenergy production and food policy, have not been extensively studied or, in some cases, considered at all.

China's renewable energy economy is also less fully understood in an international sense and therefore, it is not surprising that many empirical studies of Asian or developing country renewable energy exclude China from their analyses. For example, Gowen [29] investigates biofuel and fossil fuel economics in developing countries but excludes China; Koopmans [30] assesses the resource base of biomass energy demand and supply for South and South-East Asia countries without China; Junginger et al. [31] discuss the development in international bioenergy trade but excludes China; Peters and Thielmann [32] investigate how to promote biofuel production and its implications for developing countries, again without China. On the other hand, although Hertel [33], Rosegrant [34] and Senauer [35] include China in their samples, their focus is on the agriculture and food economy rather than on the renewable energy economy.

Therefore, both to highlight gaps and to inform future international studies, there is a need for a survey of the literature on China's renewable energy economy. The need is even more critical because of the rapid pace of change and distinctive features in China's energy economy. Consequently, the review covers both factual material on the renewable energy sector and a survey of the literature written to date. The review is designed to inform both academic and political decision making, including, crucially, those relating to environmental and sustainable development issues.

Because of the political attention paid to environmental change and sustainable development, leaders in all countries have typically demanded clear scenarios from studies of the renewable

energy economy. For example, those charged with negotiating and managing the Kyoto Protocol, including the nation's top leaders, also require accurate predictions about future renewable energy economy and its crucial impacts on fossil energy and the environment. Finally, researchers who consider the renewable energy economy need to know what has been well done and what has not, and what factual resources they can access to conduct research on China's renewable energy economy and which of these are robust. To date, however, there has been no such survey paper available for researchers or policy makers so this paper is motivated to fill that gap.

3. Renewable energy laws and policy

3.1. Unfavorable energy situation

As noted above, China is facing two severe challenges of energy shortage and increased need for environment protection. Both challenges are mainly rooted in the characteristics of China's energy supply. China's petroleum consumption has been sharply increasing, particularly since the new millennium, but China has only limited petroleum reserves [3]. While coal is abundant, and is China's major source of primary energy, its use causes severe environmental pollution. Therefore, in order to maintain fast and stable economic growth without severe environmental degradation, China has to find a sustainable policy for energy development and consumption.

3.2. Renewable energy laws

Energy laws and regulation have recently assumed a higher profile in China, against a historic background where energy saving was not given much attention. For example, the Energy-Saving Law was drafted in 1997, issued in 1998, revised in 2007 and reissued in 2008. Similarly, the Renewable Energy Law of the People's Republic of China was adopted at the 14th Meeting of the Standing Committee of the Tenth National People's Congress on February 28, 2005 and went into effect as of January 1, 2006. This Law is to promote the exploitation of renewable energy, increase energy supply, improve the energy structure, ensure energy safety, protect the environment, and attain the sustainable development of the economy and society. In fact, one year after the Renewable Energy Law went into effect, China's total renewable energy use reached 180 million tonnes coal equivalent, accounting for 7.5% of total primary energy consumption in 2006 [36].[3] Comparatively, renewable energy use was only 63.33 million tonnes coal equivalent and accounted for only 2.5% of total energy consumption in 2005 [37]. As a result, renewable energy use reduced 3 million tonnes of SO_2 emissions and saved 1000 million cubic meters of water in 2006 [36].

As China's economy has developed rapidly over the past several decades, the need to balance this growth with maintaining a healthy environment has become increasingly prominent in public debate. Therefore, the fourth session of the Standing Committee of the 11th National People's Congress adopted Economy Promotion Law of the People's Republic of China on August 29, 2008, with effect from January 1, 2009. This economic law is closely correlated to the Renewable Energy Law, and aims to facilitate recycling, raise resource utilization efficiency, protect and improve the environment and realize sustainable development.

[3] Deming Chen is former deputy director of State Development and Reform Commission at that time. Currently he is the Minister of Commerce of People's Republic of China.

3.3. Renewable energy development policies

As early as the 1970s China carried out renewable energy programs in the rural areas, but these were not motivated by shortages of fossil energy supply.[4] In contrast, most large-scale programs launched in the 1990s were motivated by the deteriorating energy balance and environmental situation. For example, the State Development and Reform Commission launched a Bright Project provide renewable power to 20 million Chinese citizens in 1996, Crop Stalk Gasification Project for the general rural area to promote and extend the crop stalk gasification techniques in 1998, Acceleration Plan for Bright Project to provide capital of ¥1800 million (approximate US$ 257 million) for solar energy and wind energy projects in 2002, and Rural Household Marsh Gas State Debt Project to construct the marsh gas construction with state debt capital in 2002 [37]. In addition, other government and international agencies also carried out renewable energy programs in China.

Despite these programs the renewable energy economy is not yet cost-competitive with the fossil energy economy. Hence the continued development of the renewable energy economy is dependent upon government support. Examples of such support include economic encouragement policy (e.g., financial subsidy, favorable taxation policy, and favorable price policy), industrialized support policy, technical research and development policy, and government renewable resources model projects.[5] However, Chen [36] noted that much more could be done to support policies for renewable energy development in China. As Zhang et al. [37] conclude, for example, there is lack of coordination and consistency in policy, weak and incomplete encouragement system, no innovation in regional policy, incomplete financing system for renewable energy projects, and inadequate investment in the technical research and development for renewable energy.

4. A review of studies of China's renewable energy economy

In this section, we first classify existing literature on China's renewable energy economy into several major themes, then we discuss the ways that renewable energy research connects to social and economic reality, and finally we identify gaps in the literature or the issues that are worthy of further attention. To provide some limits to the review and also to ensure that the studies underlying our findings and conclusions are accessible, we cover only studies that appear in major energy journals, in particular *Renewable and Sustainable Energy Review* and *Biomass and Bioenergy*, where we believe most literature on China's renewable energy economy appears, and also major agricultural economic journals, for example, *American Journal of Agricultural Economics*, *Review of Agricultural Economics*, and *Agricultural Economics*, where we believe most literature on grain-based bioenergy issues appears.

4.1. Themes in the existing literature

4.1.1. Reviewing the situation of China's renewable energy development

The main theme in the existing literature is to discuss the role and importance of renewable energy without paying much attention to interactions with other parts of the economy. Gowen [29] explores sectoral differences between biofuel and fossil fuels with regard to production costs, economies of scale, subsidies, and other economic incentives in developing countries. He argues that

[4] Actually, China's energy supply was significantly more than its demand. For example, aggregate energy production was 627.7 million tonnes standard coal equivalent while aggregate energy consumption was only 571.4 million tonnes standard coal equivalent in 1978.

[5] For other laws, regulations and general policies see Zhang et al. [37].

the development of the biofuel economy in the developing countries was motivated by rising oil price and environmental concerns since the 1970s energy crisis. Gao and Xu [38] investigate energy consumption in rural China during 1986–1987, finding that 29% of total rural energy consumption came from fuelwood, which resulted in an average deficit of approximately a quarter of fuelwood supply for the whole country. Lin [39] introduces the development and prospective of China's bioenergy technology.

After Dincer [40] published his global review of renewable energy and sustainable development, many authors have reviewed China's renewable energy and sustainable development. For example, Charlier [41] reviews China's efforts on harnessing tidal power; Chang et al. [42] present the prospects for China's renewable energy; Bhattacharya et al. [43] and Li and Hu [44] discuss China's sustainable biomass production for energy; Leung et al. [45] discuss the development and commercialization of China's biomass gasification technologies.

Recent years have seen more papers focused on China's renewable and sustainable energy economy (e.g., [16,27,46–53]). In detail, Martinot et al. [46] demonstrate China's renewable energy futures—targets, scenarios and pathways. Zeng et al. [47], Liu et al. [16] and Zhou et al. [27] investigate China's rural biomass production for energy. Huang and Yan [49] analyze the present situation and future prospect for China's hydro energy. Liu and Wang [50], Zhai and Wang [52], Hang et al. [48] and Xia and Song [53] review the experience, current scenarios and future prospects for China's wind and solar energy. Han et al. [51] summarize the lessons from China's rural bioenergy projects. Finally, the potential, current production and future scenarios of renewable and sustainable energy development in China Taiwan has also been extensively reviewed [54–60].

4.1.2. Assessing China's potential for renewable energy

Xu [61] conducts a very technical assessment of the potential for reducing atmospheric carbon by large-scale forestation and conducts a cost–benefit analysis in terms of sustainable development in China. Wang and Feng [62] propose an index system for appraising sustainable energy development in rural China. Since then, many studies have appeared for assessing the potential of China's renewable energy production. For example, Liao et al. [63] and Elmore et al. [64] investigate the spatial distribution and quantity of biomass residues as an energy resource in rural China, while Bhattacharya et al. [65] and Li et al. [66] assess the potential of China's non-plantation biomass resources. Cai et al. [18] assess biomass resources in Shanghai while Dong et al. [17] evaluate bioethanol production from wheat in Henan province of China. Koopmans [30] demonstrates the differences in biomass energy consumption and supply between different resource bases for 16 FAO member countries in Asia and concludes that China's biomass potential supply is sufficient to sustain the demand for renewable energy. Finally, Shao and Chu [67] conduct a resource evaluation of typical energy plants, focusing on the natural habitats of 10 main biofuel woody plant species and their potential for cultivation under a broad range of environmental conditions in China.

4.1.3. Providing some China's renewable case studies

There are also many case studies on China's renewable energy economy, for both particular locations and individual sources of renewable energy. For example, Zhang et al. [19] analyze the life cycle economics of fuel ethanol derived from cassava in southwest China; Zhao et al. [20] provide some development strategies to overcome the constraints of grid capacity and promote the wind power industry in Jiangsu province of China. There are more case studies focused on particular geographical locations (e.g., [21–24,26,28,68]). Specifically, Wang et al. [21,22,24] and Liu et al. [28] have surveyed the county-level sustainable energy consumption in rural China. Feng et al. [23] survey rural household bioenergy use in ecological fragile area of China.

4.1.4. Interactions with environment and food security

Since renewable energy plays an important role in sustainable energy development, many authors have estimated its contribution to the mitigation of greenhouse gas emission. For example, Wang and Feng [69] discuss biomass resources and its consumption and the effect of the discharge of greenhouse gases caused by the consumption of biofuel in China's farming area. Zhang et al. [70] estimate the effect of household biogas construction on emission reduction of CO_2 and SO_2 in rural China. Lin et al. [71] introduce the ambitious target set by China's 11th Five-Year Plan for energy-efficiency improvement, which makes the Chinese effort one of the most significant carbon mitigation efforts in the world today. Liu and Ma [72] analyze the impacts of microalgae-based fuel methanol on environment in China. However, fewer studies investigate the effect of biofuel production on the grain markets in China. For example, Yang et al. [73] and Huang et al. [74] found world biofuel production has significantly increased China's domestic grain prices. They found biofuel production had made grain (wheat, maize and soybean) prices raise by 25–45% between 2005 and 2008.

4.2. The implications drawn from existing studies

One reason why much of the current literature is still only discussing the role and importance of renewable energy, rather than engaging in more substantive modeling tasks, is that there is considerable uncertainty about the future path of the renewable energy economy in both China and more generally. Consequently, studies which attempt to be forward-looking may become too speculative. There are at least six sources of uncertainty about renewable energy development in China, which may be classified as follows.

First, the prospects for renewable energy seem uncertain because various constraints are still considered as possible barriers to biofuel energy development. For example, Nonhebel [75] questions whether there is enough land to grow crops for both renewable energy and food supply. In fact, the feasibility of biofuels was still being questioned as late as 2009 [76]. In keeping with this pessimism about biofuels, it was not until 2006 that study began on commercial development of crop-based bioenergy projects in China [77]. Similarly, it is only recently that analysts have realized that renewable energy may be an efficient mechanism to improve the macro economy [78].

This tentative nature of the literature is also a feature of studies that focus particularly on China. For example, it was not until 2008 that studies discuss perspectives on China's fuel ethanol consumption and trade [79]. Only in 2009 does a discussion begin on how to reconcile China's sustainable energy use, environmental stewardship and social development due to the challenges of rapid economic growth [80]. At the same time, Zhang et al. [37] are still discussing the opportunities and challenges for China's renewable energy policy. As can be seen from these studies, many issues still appear to be unclear for China's renewable energy development.

Second, researchers, both domestic and international, have just started to investigate the relationships between biofuel energy production and world grain prices. Similarly, the relationship between world food security and grain-based bioenergy production in China has just recently attracted scholarly attention. For example, Yang et al. [73] and Huang et al.[6] [74] just began to study China's

[6] Noted that this research group of people comes from The Center for Chinese Agricultural Policy, Chinese Academy of Sciences, and they have just started to study biofuel energy production and its effects on grain prices and food security for China since 2007.

biofuel energy production and its effect on domestic grain prices and food security recently. This late realization is even true for many international scholars [33,81–86], who only investigate the relationship between biofuel production and food supply and do not consider interactions with the environment and with renewable and sustainable energy development.

Third, renewable energy development policies are as yet incomplete and even may be unfeasible. Literature in this vein includes, Zhang et al. [37] who review the opportunities and challenges for China's renewable energy policy and Huang [87] who provides a series of policy mechanisms to finance rural renewable energy development in China. This potential infeasibility is also true for the rest of the world. For example, Tyner and Farzad [88] investigate policy alternatives for the future U.S. renewable energy development and Rosegrant [34] studies the impact of U.S. biofuel policy on developing country agriculture and food security.

Fourth, the potential resources available for renewable energy development is still unclear, particularly for grains destined for biofuel production. China is the third largest producer of ethanol in the world and bioethanol production reached 1.3 million tonnes in 2006. Maize is the primary feedstock in the Northeast and wheat also is used as a feedstock in the newest biofuels plant in Henan province. In China, about 4.8 million tonnes of maize, accounting for 3.4% of total maize output, was used to produce bioethanol in 2006 [89], while approximately 4 million tonnes of wheat, accounting for 4.4% of total wheat output, was used in the production of biofuels in 2007 [73]. Expanding biofuel production has made China become a net grain importer. Therefore, Chinese leaders have begun to review the biofuel development policy and voluntarily dampened domestic biofuel production, at least in the short run [73]. As a result, policy and regulation are frequently pendulous for biofuel development in China. The reason for this lack of consistency is rooted in the concerns political and economic concerns with food security and social stability. The question of how much grain can be used for biofuel production without significantly affecting the domestic grain market and social stability is one of the most important facing biofuel development policy in China and will be one of the most likely causes for any reversal in policy.

A fifth source of uncertainty about the future path of renewable energy results from the compartmentalized nature of the scholarship in this area. On the one hand, there are agricultural economists who are worried more about grain markets, food security and social stability, while on the other hand there are renewable energy economists who are concerned more with the environment and sustainable energy development. These disciplinary differences in how to treat biofuel production are evident in their publications reviewed here and the academic journals their studies appear in. For example, Yang et al. [73] and Huang et al. [74] investigate the effect of biofuel production on grain prices in China, but their results have nothing to do with either the environment or with renewable and sustainable energy development. Likewise, many scholars study the potential of biofuel production but never mention the effect that biofuels may have on the grain market in China (e.g., [69–72]). Indeed, we have not found any specific study that simultaneously focuses on China's biofuel production and its effect on grain market prices and renewable energy. Some studies only generally investigate the issues relevant to biofuel production, renewable energy, environment and food supply [35,84].

Finally, while there are rich datasets with details on rural biomass energy consumption in China, these have not been well utilized by existing studies of China's renewable energy economy. For example, the information on non-commercial energy consumption for rural residents in China has been available for a long time. These data cover the main renewable energy sources (firewood, crop residues and biogas) for rural China and are published by the China Statistical Publishing House since at least 1999. However, it is surprising to find some existing studies focused on the assessment of rural biomass energy consumption based on other, less comprehensive, data sources (e.g., [16,42]).

4.3. Missing issues in existing studies

As can be seen from the above, while the role and situation of the renewable energy economy has been well documented, more advanced studies of the economics and econometrics of renewable energy, particularly with a focus on China, are still in their infancy. While there is much to be done by scholars to provide a better understanding for China's renewable energy economy, five specific suggestions are made below.

First, the relationship between biofuel and grain production has not well investigated and econometrically analyzed for China. While Escobar et al. [84] and Senauer [35] discuss issues of biofuel production and food security more generally, they do not pay attention to the situation in China. Indeed, no one has investigated biofuel production, grain supply, food security, and renewable and sustainable energy development for China as a whole.

Second, more economic and policy analytical scenarios are needed to help China's policy-makers guide renewable energy economic development. Such studies need to pay particular attention to the grain-based biofuel energy production. China has become the third largest biofuel producer in the world but whether there are any comparative advantages in bioenergy production has not been fully investigated for China. This issue is important because although there is a potential for China to carry out grain-based biofuel production but there is potential need for food grain. However, this issue has been extensively studied for USA and Brazil [90–92].

Third, the demand characteristics for renewable energy and the substitution possibilities with fossil energy need to be estimated. The literature is well behind in this regard and in fact, it is only recently that China's fossil energy demand and substitution possibilities have been completely estimated by Ma et al. [2,93]. Therefore, it is not surprising to find that there have been no such estimates for the substitution possibilities between renewable and fossil energies for China, especially the substitution between biofuel energy production and food grain supply.

Fourth, renewable energy cost–profit analysis should be accurately and extensively investigated because it is the foundation for ones to estimate possibilities of demand and substitution for renewable and sustainable energy development. Although U.S. and Brazil biofuel production cost and profit analyses have been well calculated [91], we have not found any cost and profit analysis for China's biofuel production.

Finally, the relation between grain-based biofuel production and rural income growth should be fully assessed for China because grain-based biofuel production not only increases energy supply but also raises grain prices and in turn promote rural income growth [49]. This is particularly important for China because approximately 40% of total population engages in agricultural production, which accounts for nearly 60% of rural household business net income per capita [1]. Although some are concerned of the effect of biofuel production on grain prices and other are concerned of the effect of biofuel production on renewable energy supply and energy prices, no one is interested in the effect of biofuel production on rural income growth in China, which is surprising given the importance of grain production in China.

5. Areas for future research

According to the existing studies of the renewable energy economy surveyed above, we consider that the following topics merit future attention.

5.1. Assessing the potential of grain-based biofuel production

The potential of biomass energy resources, including various crop residues and firewood, to contribute to energy production is relatively easy to calculate as their energy conversion coefficients and biomass inputs are known given existing renewable energy processing techniques. However, it is harder to assess the resource potential of grain-based energy production in part because although it is known how much total grain is available, it is uncertain how much grain is available for biofuel energy production because of its alternative use as a food. Answers to such questions depend on the degree of market-oriented grain production and consumption, where marginal output may be considered as an indicator of the potential for grain-based biofuel production.

5.2. Assessing the economy-wide effects of biofuel production

As can be seen from existing literature, energy economists have paid more attention to the effects of renewable energy production on the environment and sustainable development (e.g., [72,86]), while agricultural economists have paid more attention to the effects of renewable energy production on grain supply and food prices (e.g., [34,35,49,73,81,85]). However, renewable energy, in particular grain-based biofuel, production has effects on not only energy supply and the environment, but also grain supply, food prices and rural income growth. Therefore, in order to assess the potential of biofuel production, we need to investigate the comprehensive effects of China's biofuel energy production. We need to investigate the effects of biofuel energy production on downstream and other industries (such as transportation, coal mining, chemicals and petroleum industries, etc.) as these industries are either energy-intensive or energy producing and are therefore affected by biofuel energy production. In the case of grain, a question might be asked as to what is most important, food or energy?

5.3. Undertake surveys of biomass utilization in rural China

As can bee seen from the previous literature surveyed above, there are many case studies, both domestic and international, of the potential uses of biomass resources (e.g., [64,65,94]). However, there are fewer surveys that investigate the current utilization of biomass resources in China and therefore there is an incomplete picture of how biomass resources are utilized in rural China. Moreover, most existing surveys concentrate on a small number of counties [18,24] leaving much of rural China unsurveyed, although there are some studies providing general information on rural energy consumption based on published rural energy consumption data. However, the largest producing and consuming areas of biomass resources have not been surveyed for example, Henan, Shandong, Anhui, Sichuan and Jiangsu, which are major crop producing areas with their shares of national grain production being 10.5, 8.5, 5.8, 6.0 and 6.2%, respectively. As a result, they produce large volumes of crop residues and biomass resources in rural China. To date, however, we have no clear idea how these crop residues are utilized.

5.4. Estimate the substitution possibilities of biofuel and fossil fuels

The importance of renewable energy production relies mainly on its substitution possibilities for fossil energy resources. The more significant possibilities renewable energies have to substitute for fossil energies, the more important renewable energies become. We see this, in particular, in the case of biofuel substitutes for petroleum. Many previous studies assess the potential and discuss effects of renewable energy production on the environment, energy supply and food markets [34,35,49,70,78,85,95], however, they fail to address how large are the substitution possibilities between renewable energy and fossil energy. There are a small number of papers, see for example, Ma et al. [2,93], that estimate the demand for and substitution of fossil fuels, however, this has not translated into similar estimates for renewable energies and this area of research requires urgent attention.

5.5. Undertake feasibility studies of renewable energy investment and reconsider policies and laws

In the area of feasibility studies and legal/policy changes, there are a few topics worthy of further investigation for example, (i) cost–benefit analysis for biofuel and biomass energy project investment; (ii) renewable energy laws and their effects on the promotion of renewable energy development and environmental protection; (iii) policy reforms and changes to the renewable energy economy in rural China and their effects on rural income growth. The choice of these issues is driven by the fact that some renewable energy programs appear not to operate effectively or efficiently, where some even cease operation soon after construction. Technology may play a role in such outcomes, as might the price of substitutes, however, careful pre-project appraisal of renewable energy projects is crucial. Rural renewable energy programs, such as biogas, were established as early as in the 1960s. At that time rural renewable energy programs were generally not motivated by the shortage of energy supply or for environmental reasons, more often as part of a political program or work scheme. Whether such motives underpin new renewable energy programs is unclear, and a policy that requires pre-project economic and environmental impact analysis would go some way to understanding the motivation behind new projects.

6. Some suggestions

To better understand China's renewable energy economy, it is crucial for researchers to undertake rigorous and extensive research into for example, the substitution possibilities between renewable energies and fossil energies; the effects of renewable energies on the environment, energy markets, agricultural markets, and rural income growth. Such extensive research is required because China's renewable energy economy is still in its infancy and there are many issues that need to be investigated and applied.

To conduct more comprehensive research into the effects of China's renewable and bioenergy production on fossil energy and agricultural markets, renewable energy economists and agricultural economists need to cooperate and integrate their separate results. Renewable energy researchers and economists need to pay more attention to the effect of renewable energy on food security and agricultural markets and agricultural researchers and economists need to pay more attention to the effects of renewable energy production on the environment and energy markets. This is particularly true for grain-based biofuel production where in China's case, more grain is needed to feed a growing population. The issue of increased petroleum imports and its effects on China's economy and environment are well documented and high on the political agenda. The issue of growing demands for grain (food) imports is at least as important and in the area of renewable energy, the two competing uses for grain intersect.

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